Palynological Evidence for Holocene Environmental Change and Uplift on Wireless Hill, Macquarie Island

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Wireless Hill, at the northern end of subantarctic Macquarie Island, has a raised beach on its western edge at an altitude of about 100 m. The beach is overlain by a deposit of organic-rich sands grading upward into peat, the sequence having a basal date of approximately 5500 years BP. Palynological and other microfossil studies have revealed changes in the vegetation on the site, interpreted as indicating changes in the environment of the site rather than reflecting climatic change in the region.

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INTRODUCTION

The location of subantarctic Macquarie Island (158°57′E, 54°30′S) makes it a potentially sensitive recorder of Quaternary climatic and tectonic events. The island, a fault-bounded and cross-faulted block of ocean floor material (Varne and Rubenach, 1972) is a high point on the Macquarie Ridge, the junction of Indian-Australian and Pacific tectonic plates (Summerhayes, 1974). The area is seismically active. The Antarctic Convergence at present lies just south of the island but was north of it 18000 years BP (Hays, 1983). The climate today is hyperoceanic, cool, moist and windy.

The island was glaciated during the last glacial maximum, but the severity of glaciation is debated. The rather limited glaciations postulated by Colhoun and Goede (1974) and Löffler and Sullivan (1980) appear more likely than glaciation by an overriding ice sheet coming from the west (where there is now no land) as postulated in Mawson (1943). Taylor (1955) accepted the theory of ice-sheet glaciation and considered the island's present flora as due to long-distance recolonization in post-glacial times. Bunt (1956) claimed to recognize fossil pollen remnants of a pre-glacial flora, differing from the present one, but suggested that some elements of this flora may have survived the glaciation in refugia on a then-larger Macquarie Island. The evidence for Bunt's conclusions is unclear. More limited glaciations described by recent authors would not have involved elimination of the biota, since substantial refugia would have occurred within the present limits of the island. Presence of similar refugia on South Georgia is suggested by Barrow (1978).

The timing of the island's emergence above sea level, and the rates of uplift of the island are also matters of uncertainty. McEvey and Vestjens (1973) dated penguin bones in beach deposits. Colhoun and Goede (1973) dated basal peats on marine terraces close to sea level. They assumed immediate peat formation on any area lifted above wave influence to calculate a maximum rate of terrace uplift of 4.5 m/1000 years. Using McEvey and Vestjens' penguin bone dates, they calculated a minimal rate of 1.5 m/1000 years, and suggested a mid to late Pleistocene emergence of the island. Blake (Mawson, 1943), from observation of wreckage on west coast terraces,
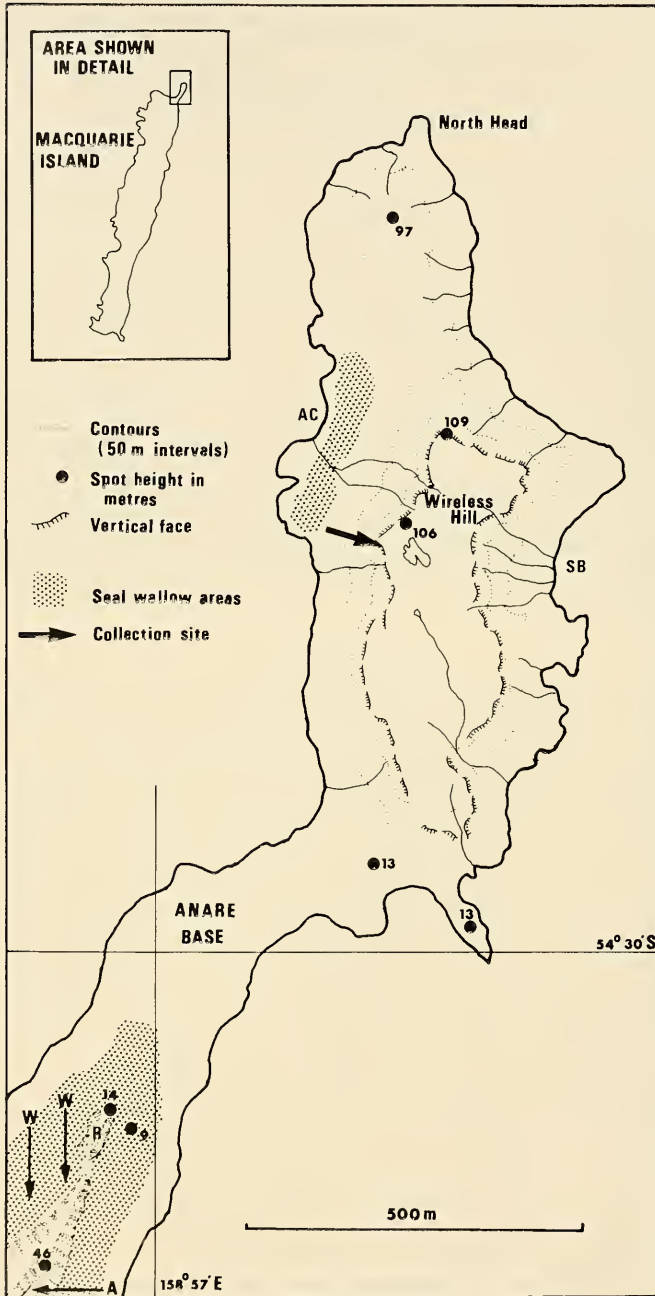
Fig. 1. Map showing location of collection site. AC = Aerial Cove; SB = Secluded Beach; A = Collection site of mat of *Amblystegium* on Doctor's Track; W = Seal wallow sampled for pollen analysis; R = Razorback Hill.

suggested that uplift was extremely rapid and probably measurable in the short term. Bunt (1956) had suggested the island dated from early Tertiary or even Mesozoic times. Miocene marine oozes on the island (Quilty et al., 1973) make this unlikely.

Quaternary studies on Macquarie Island, apart from studies of glacial landforms (Colhoun and Goede, 1974; Löffler and Sullivan, 1980) and lakes (Peterson, 1975) have until recently been few, and there are as yet no clear indications as to whether any substantial vegetational change has occurred during the Holocene. Considerable interest is now being shown in the island's Holocene history. Selkirk and Selkirk (1983) reported early to mid Holocene ^{14}C dates for organic deposits from a number of sites and have described fossil mosses from two lacustrine deposits (Selkirk and Selkirk, 1982). Salas, Peterson and Scott (in preparation) are making palynological studies of two cores from Scoble Lake, near the northern end of the island. Ledingham and Peterson (in preparation) are studying raised beaches at several localities.

As the only land in a vast area of ocean, Macquarie Island supports huge breeding populations of seals and sea-birds which have a considerable effect on the vegetation over wide areas (Mawson, 1943; Taylor, 1955; Gillham, 1961; Jenkin, 1975). Evidence presented here of animal-modified vegetation preserved in Holocene deposits on top of Wireless Hill, suggests that Wireless Hill, a small fault-bounded segment of the island, appears to have undergone very rapid tectonic uplift at rates 3-4 times greater than the maximum proposed for marine terraces on the main island mass to the south. It therefore seems that uplift of Wireless Hill has been essentially independent of uplift of the island as a whole.

MATERIALS AND METHODS

The site

Samples analysed were collected from an exposure of peat and organic-rich sand on the western edge of Wireless Hill, a steep-sided headland whose flat top is mainly about 100 m a.s.l. (Figs 1, 2). The collection site is at the edge of the plateau, very close to the steep western seaward slope. Samples were collected from a face freshly cut into the exposure, the face extending downwards into a pit, at the bottom of which are beach cobbles. These cobbles clearly represent an extension beneath the deposit of the well-preserved raised beach (R. Ledingham, pers. comm.) which is exposed on the slope immediately north of the collection site (Figs 1, 3).

There are several vegetation types on and around Wireless Hill at present. In Aerial Cove (Fig. 1) there is a low-level beach terrace with *Poa foliosa* tussock and elephant seal wallows. At the base of the cliff behind Aerial Cove, and in sheltered parts of the steep slopes above Secluded Beach there is extensive growth of *Stilbocarpa polaris.* *Poa foliosa* tussock covers most of the slopes of the headland. The top of Wireless Hill is almost flat (Fig. 2) except for one small tarn and a wind-scoured area forming a slight depression at the head of a gully draining from the flat top to the eastern slopes. *Poa foliosa* grows over some of the plateau, and *Stilbocarpa polaris* occurs in sheltered spots near the slight depression. Most of the plateau surface supports a low herbfield which includes *Agrostis magellanica, Festuca contracta, Luzula crinita* and scattered plants of *Pleurophyllum hookeri.*

The isolated plateau of Wireless Hill is linked to the main island by a narrow (about 200 m wide) low-lying (mostly about 5 m a.s.l.) isthmus. During their breeding season numerous elephant seals occupy beaches on both sides of the isthmus and have created large wallow areas between the beaches and the ridge of Razorback Hill (Figs 1, 4). These wallow areas carry a mixed *Poa foliosa- Poa annua- Cotula plumosa- Callitriche antarctica* community with large bare areas (Figs 4, 5).
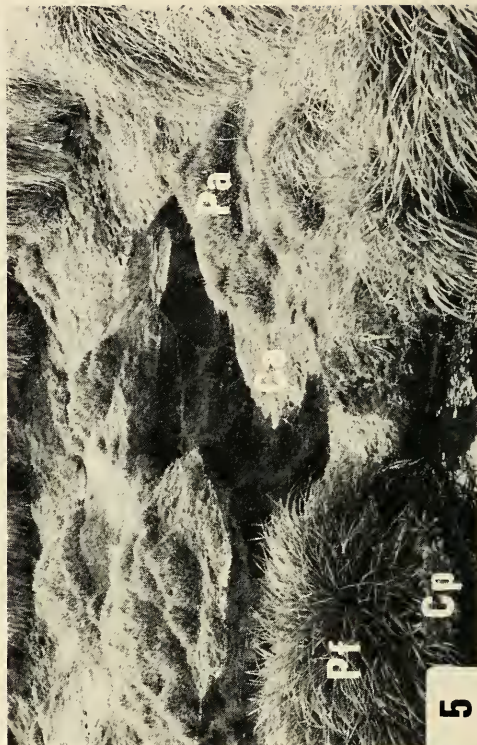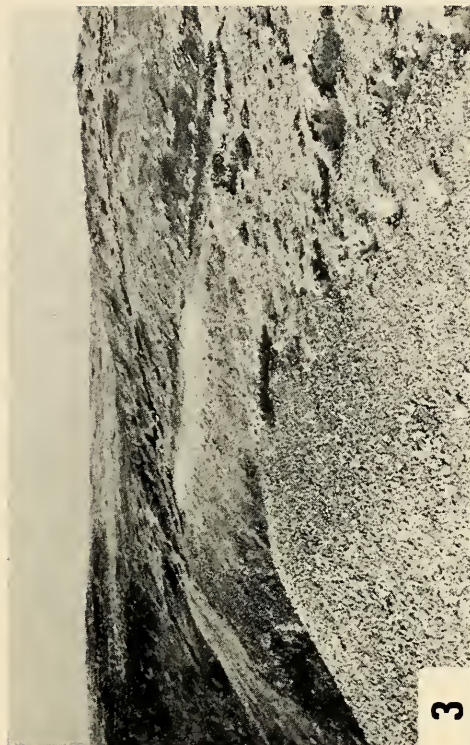
Sample collection and treatment

The profile sampled totals almost 4 m, the top of the profile (0 cm in Fig. 6) being defined as the peat-soil surface under living vegetation at the site. This is very close to 100 m a.s.l. Samples from 0-270 cm were collected in plastic tubes, internal diameter 2.5 cm, pushed horizontally into the freshly exposed face. All other samples were removed with a spatula into plastic bags. Each sample represents about 2 cm vertical extent. Larger samples for ^{14}C dating (vertical extent shown to scale in Fig. 6) were transferred to plastic bags. A peat monolith straddling the 85 cm level was collected.

Each sample was divided into sub-samples for (1) pollen analysis, (2) analysis of the siliceous fraction, (3) total mineral content determination and (4) stratigraphic analysis.

For pollen analysis ca 5 cc of material were boiled in 10% KOH and then acetolysed using standard palynological techniques (Brown, 1960). Almost all pollen preparations required treatment with HF due to the high mineral content of most horizons and the presence of very abundant opal phytoliths, diatom fragments and chrysomonad cysts.

For analysis of the siliceous fraction ca 5 cc of material were boiled sequentially in concentrated hydrochloric, nitric and sulphuric acids, samples being centrifuged between successive acid treatments (Lacey, 1963). Coverslip strews of the siliceous fraction were mounted in Naphrax mounting medium for observation.

Total mineral content of 5 cc samples was determined by oven-drying at 80°C followed by ignition of the samples at 700°C. Qualitative estimates of the relative abundance of biogenic silica were made from strews of the siliceous fraction. No attempt has yet been made to determine quantitatively the ratio of biogenic silica to other mineral matter.

Stratigraphic analysis was carried out using ca 2 cc samples put in a petri dish with water and studied under a dissecting microscope. Identifiable plant remains and other components of the sample were recorded. Detailed analysis of the peat monolith spanning the 85 cm level was carried out in the same way. Results of these microscopic examinations appear in Figs 6, 7.

A subsample at 85 cm was boiled for one hour in concentrated nitric acid and then washed with 5% ammonium hydroxide as a charcoal verification test (Singh *et al.,* 1981). Macroscopic charcoal particles showing cellular structure were dissected from the matrix and studied with a scanning electron microscope.

A comprehensive reference collection of pollen, fruits, seeds and spores of the extant vascular flora was made during the summer of 1979-1980. Reference pollen samples, usually taken from anthers of several different plants of the species, were acetolysed and mounted in glycerine jelly.

RESULTS OF ANALYSIS

Three main stratigraphic divisions are distinguishable in the profile (Fig. 6). From 0-175 cm thin layers of well-humified peat alternate with layers of sandy peat. A thicker layer of well-humified peat occupies the 175-232 cm zone. Below 232 cm is a predominantly sandy matrix with interbedded layers of peat. The peat layers may well

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Fig. 2. Wireless Hill, photographed from the south east, from deck of ship.

Fig. 3. Raised beach at 100 m a.s.l. on western edge of Wireless Hill.

Fig. 4. Southern end of isthmus, from Doctor's Track. Note elephant seals on beach (arrow) and wallow areas amongst *Poa foliosa* tussocks, between beach and Razorback Hill and ridge.

Fig. 5. Seal wallow showing associated vegetation. Pf = *Poa foliosa,* Pa = *Poa annua,* Cp = *Cotula plumosa,* Ca = *Callitriche antarctica.*
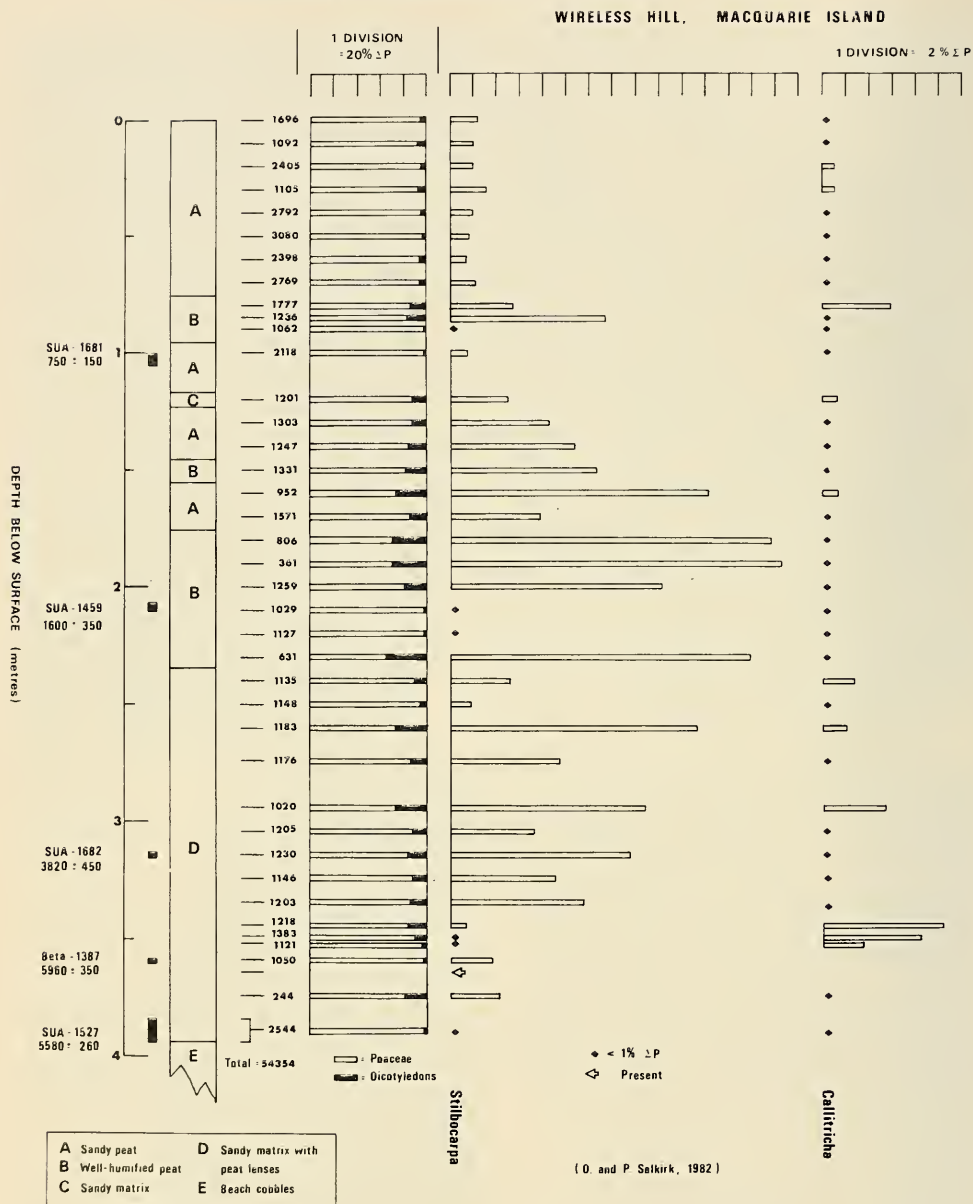
Fig. 6. Pollen diagram and stratigraphy of profile.

occur as lenses within the sandy matrix but have not been traced laterally to decide if this is so. From 384-394 cm the mineral matrix contains sand- to gravel-sized rounded balls of peat. The peat balls probably represent erosion of a pre-existing peat and incorporation of its fragments in the matrix. Whether erosion and redeposition occurred in situ or whether the peat balls were carried some distance by wind or water

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PEAT STRATIGRAPHY   (K Griffin, 1982)

Fig. 6. (Continued)

is unknown. Wind ablation of peat occurs on the island today during short relatively dry periods (J. Scott, pers. comm.).

Radiocarbon dates shown in Fig. 6 have been calibrated following Klein *et al.* (1982). Table 1 shows various radiocarbon dates obtained from the profile. There is no evidence in either the stratigraphy or dating of any prolonged hiatus in deposition since

TABLE 1

Depth (cm)	Code Number	Conventional Radiocarbon Age (years bp)	Calibrated Age (years BP, 95% confidence level)
384-394	SUA-1527	4880 ± 90	5580 ± 260
	SUA-1527 HA*	4610 ± 100	5300 ± 300
358-360	Beta-1387 (soluble fraction)	5140 ± 140	5960 ± 350
313-315	SUA-1682	3490 ± 210	3820 ± 450
206-210	SUA-1459	1600 ± 130	1600 ± 350
	SUA-1459 HA	1300 ± 90	1210 ± 160
100-105	SUA-1681	760 ± 100	750 ± 150

*HA = humic acid fraction

the profile began accumulating some 5500 years BP. There is some wash down through the peats of humic acids, as evidenced by the paired dates for insoluble and soluble fractions of SUA-1527 and SUA-1459.

At and below 274 cm there are large numbers of corroded and fragmented grass pollen grains. Only intact grass grains have been included in the pollen sum. In general, dicotyledon pollen appears to have been less susceptible to corrosion. *Callitriche* pollen, however, appears to corrode fairly rapidly, but remains identifiable even when corrosion is rather severe. No pollen was recoverable from the 110 cm sample. The pollen sum includes all local and exotic pollen grains, but excludes spores.

Results of the pollen analysis are given in Fig. 6. Exotic pollen grains occur throughout the profile, but in very small numbers, never more than 0.3% of the pollen sum. Podocarp grains are the most common exotic type, and there are occasional myrtaceous pollen grains. Several unknown types of exotic pollen were encountered. No attempt has been made to identify them because of the extremely small numbers involved. Fern spores occur even more rarely than exotic pollen. Of the thirteen encountered in a total of some 54000 spores and pollen grains counted, two are referable to *Hymenophyllum* and two to *Grammitis*. The rest are monolete spores which could represent *Polystichum* and/or *Blechnum*. All four fern genera are represented in the island's present flora. Spores of *Lycopodium* also occur rarely, and are present from the base of the profile. Because of the very low frequency of exotic pollen grains, fern and *Lycopodium* spores, they have not been included in the pollen diagram.

Grass phytoliths make up a significant proportion of the siliceous fraction of all samples. Diatoms and chrysomonad cysts are also common throughout. Diatoms are common on leaves of living *Poa foliosa* on Macquarie Island, and may well occur on leaves of most plants where conditions remain constantly moist. Chrysomonad cysts have been observed on the base of living *Poa foliosa* leaves and are common in samples of surface litter.

A survey of the diatoms in the profile (H. Brady, pers. comm.) shows close correspondence between preservation of diatoms and of pollen. At levels in which pollen is poorly preserved, diatoms are too broken for meaningful counts (e.g. 100-160 cm, 230-240 cm, 359-375 cm). These correspond with sandy layers in the stratigraphic column. Marine diatoms are present in low frequency (1-11% of the total diatom count) throughout the profile, presumably from wind-blown spray.

One diatom assemblage stands out in startling contrast to those in the rest of the profile. *Pinnularia atwoodii* is present throughout the profile in low frequency (0-4%) but at 394 cm, 344 cm and 294 cm, dominates the assemblage (12-19%). When
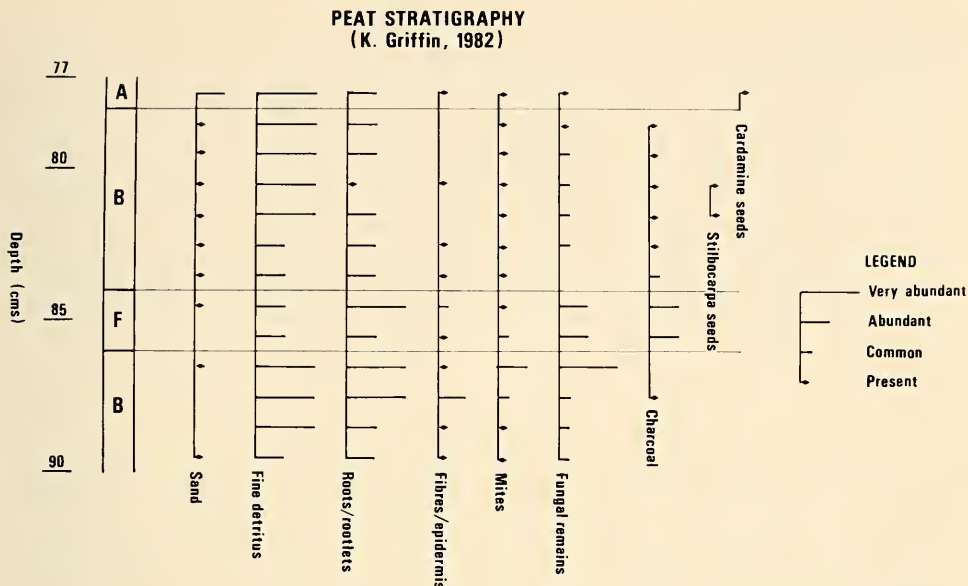
PEAT STRATIGRAPHY
(K. Griffin, 1982)

Fig. 7. Detailed stratigraphy of profile straddling charcoal layer at 85 cm. F = charcoal-rich layer. Other symbols as in Fig. 6.

samples from five modern seal wallows were examined it was found that in all five, there is only a small (less than 1%) marine component. In three of the five, *P. atwoodii* is common, suggesting that this species thrives in a well-manured environment, such as seal and/or penguin-disturbed sites.

Plant macrofossils referable to specific genera occur most commonly in the well-humified peat layers above 200 cm. *Stilbocarpa* seeds first appear once pollen of that genus has reached its peak, but reappear throughout the upper part of the profile, even though *Stilbocarpa* pollen percentage declines.

Especially interesting is the occurrence in this profile from a hyperoceanic subantarctic island of two charcoal layers. There is a very distinct charcoal layer at 85 cm, and a less distinct charcoal layer at 30 cm. The layer at 85 cm has been traced a short distance laterally from the sampling site, but its full extent is unknown. A detailed
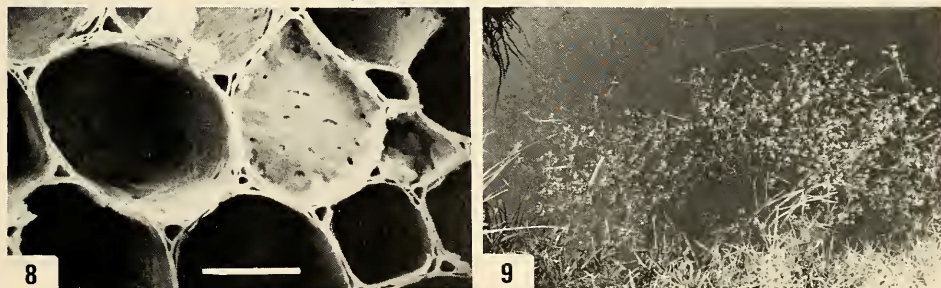

Fig. 8. Scanning electron micrograph of charcoal fragment from 85 cm depth. Note distinct layering of cell walls in cross-section. Scale line 25μm.

Fig. 9. *Callitriche antarctica* growing as an aquatic in an abandoned or little-used seal wallow.

stratigraphic study of the peat straddling the 85 cm zone is shown in Fig. 7. Movement of charcoal particles up and down the profile from the main layer is probably due to bioturbation. A test used to verify the presence of charcoal in palynological preparations (Singh *et al.*, 1981) indicates that the small black particles seen in the pollen preparations, and the macroscopic pieces visible in the peat, are indeed charcoal. The material even withstands the acid digestion technique used to prepare the siliceous fraction of samples for study. Macroscopic pieces are black, brittle, and have a characteristic sheen as seen in modern charcoal. Fig. 8 shows a scanning electron micrograph of a charcoal specimen, probably the remains of an axis such as a stalk of a *Poa foliosa* inflorescence. The specimen received no treatment other than the cutting of a flat face on the specimen with a razor blade and coating for scanning electron microscopy.

DISCUSSION

The profile analysed is likely to record vegetation change of a quite local nature. The site is on the western edge of Wireless Hill where, as is true for the whole island, winds are overwhelmingly north-westerly to south-westerly (Mawson, 1943: 30), blowing across thousands of kilometres of open ocean. Winds from other directions are uncommon, but when they do occur are usually gale force. There is no reason to assume major change in this wind pattern over the past 5000 years, so one could reasonably infer that pollen in peats on Wireless Hill would be derived mainly from vegetation close to the site or blown up to the site from the slopes and strand below. This inference appears to be justified since the pollen diagram shows an almost complete absence of a wide regional component. Barrow (1978) found that pollen in surface litter samples on South Georgia is principally derived from plants growing in communities very near sample sites. In the profile studied here *Azorella* pollen, for example, occurs only sporadically and in very low frequency, although *Azorella selago* is dominant in the feldmark community which covers about half the main part of Macquarie Island to the south, at altitudes above 250 m. *Azorella* pollen is common in surface samples in herbfield and feldmark situations on the main island (M. Salas, pers. comm.).

That the vegetation on or close to the site has been grass dominated for the past 5000 years or so is clear. Grass pollen is always present in huge quantities when compared with dicotyledon pollen, intact grass anthers have been encountered in all pollen preparations, and the relative abundance of immature grass pollen grains suggests a local source for the pollen. Grass phytoliths make up a significant proportion of the siliceous fraction of all samples. Phytoliths almost certainly represent grass growing on or close to the site, since they have little chance of becoming airborne once they rot out of the decaying foliage which has become incorporated in the surface litter layer. In dry, continental areas phytoliths may become airborne in dust, possibly being carried some distance (Baker, 1959a, b), but would be likely to remain in situ on Macquarie Island in the moist environments suitable for peat formation.

Vegetational changes recorded in the profile are not readily interpretable in terms of climatic variation. There are no major variations in 'upland' or 'lowland' components such as have allowed identification of climatic change on other subantarctic islands (Bellair and Delibrias, 1967; Bellair-Roche, 1972; Schalke and van Zinderen Bakker, 1971; Young and Schofield, 1973; Roche-Bellair, 1973, 1967a, b). Barrow (1978) could detect no evidence of major climatic variation over the past 10000 years on South Georgia by means of pollen analysis even though there was probably a readvance of valley glaciers about 5500 years BP (Stone, 1976).

The sequence of events recorded in the samples can most readily be interpreted in terms of localized vegetational changes resulting from uplift of the site from a position close to sea level to its present altitude. That the cobbles underlying the deposit are those of an ocean beach rather than a lake-shore beach is clear. Only a substantial lake at 100 m would allow sufficient wave action to form a well-developed beach, and such a beach would be best developed at the lake's eastern end, due to prevailing winds. Interpretation of the cobbles as those of a lakeside beach would imply loss of an extensive area of land to the west of the present Wireless Hill. For this there is no evidence. The basal sequence of the profile gives a clear indication of animal-disturbed vegetation, and taken together, both pollen and diatoms present in the basal samples point to elephant seals as the most likely cause of this disturbance.

The peaks in *Callitriche* pollen between 120 and 352 cm almost certainly represent periods of modification of the vegetation by animals. On Macquarie Island at present, *Callitriche* appears only to be locally abundant where there is animal disturbance and manuring of the vegetation. It is most common around elephant seal wallow areas, growing both on the ground between wallows, and as an aquatic plant in the water of abandoned and infrequently used wallows (Figs 5 and 9). Taylor (1955) described *Callitriche* as growing on very wet soils and in pools at low elevations, commonly colonizing abandoned seal wallows. Gillham (1961) pointed out the close association between *Callitriche* and animals, recording it as most common on and near seal wallows, and common in wet gentoo penguin rookeries on the 'featherbed' at Handspike Point. J. Scott (pers. comm.) reports *Callitriche* and *Poa annua* as locally luxuriant near abandoned gentoo nesting sites close to the sea, and notes that such sites are also commonly disturbed by elephant seals. At higher altitudes, similar but less luxuriant growth of *Callitriche* and *Poa annua* occurs in association with giant petrel colonies, although both plants are rare in the surrounding undisturbed tussock grassland (J. Scott, pers. comm.). *Callitriche* can occur also in small quantities in rockhopper penguin rookeries which may be at considerable altitude. Whether *Callitriche* can be associated with albatross nests on Macquarie Island is still unclear. Although *Callitriche* acts as a colonizing species on peat surfaces bared by landslip, providing 15-20% cover eighteen months after slippage, it appears to be absent from old well-vegetated slip sites (J. Scott, pers. comm.).

On other subantarctic islands, *Callitriche* also seems closely linked with animal disturbance. On South Georgia, *Callitriche* is almost entirely confined to seal wallow areas in *Poa* tussock grassland, but also occurs in 'meadow' bogs enriched by bird excreta (Smith, 1981). On Marion and Prince Edward Islands, *Callitriche* is locally important in areas manured by seals, rockhopper penguins and albatrosses, forming part of a community called by Huntley (1971) a biotic complex. Croome (1971) studied effects of albatross manuring on Marion Island, and found *Callitriche* abundant near albatross nests. Smith (1978) found that *Callitriche* occurred only in manured sites on Marion Island. Schalke and van Zinderen Bakker (1971) interpreted *Callitriche* peaks in their pollen diagrams as due to albatross nesting.

The peaks in *Callitriche* pollen at 20, 30 and 80 cm (Fig. 6) may represent bird activity. Black browed albatrosses and giant petrels have nested on Wireless Hill quite recently (G. Johnstone, pers. comm.) and could cause local flushes of *Callitriche*. However the peaks in *Callitriche* at 30 and 80 cm are also associated fairly closely with charcoal layers in the peat, discussed below.

If *Callitriche* pollen is to be used as an indicator of environmental conditions at a very localized site, then it is necessary to establish that its pollen is not transported far from its origin. The possibility of large inputs of windborne pollen needs to be eliminated. Analysis of pollen in a surface litter sample, a moss mat and a modern seal

wallow (Fig. 10) indicates that *Callitriche* peaks in the pollen record almost certainly represent vegetation on or close to the site. The surface litter sample was collected from the top of the profile analysed. *Callitriche* contributes less than 1% of total pollen and only 10% of total dicotyledon pollen. On the coast below and to the west of the collection site is a seal wallow area (Fig. 1) which provides a source of *Callitriche* pollen which has, however, not been blown the 100 m up to the site on prevailing winds. Similarly, analysis of a mat of *Amblystegium* at 80 m a.s.l. on the Doctors Track (Fig. 1), above extensive seal wallow areas on both sides of the isthmus (Fig. 4) yielded *Callitriche* at levels of less than 1% on both a total pollen and dicotyledon-only basis. The *Amblystegium* mat was collected when extensive swards of *Callitriche* in the wallow areas were in full flower, and when prevailing winds were favourable for pollen transport.

    Both the litter and the moss mat samples, taken in conjunction with an analysis of pollen from a modern seal wallow (Fig. 10), indicate that most *Callitriche* pollen is deposited very locally, and that transport to other sites is very minor. This is perhaps not surprising for a plant which grows as a low mat on very wet soils, or as an aquatic (Fig. 9) in a hyperoceanic environment with almost daily precipitation.

    We interpret the main *Callitriche* peak at 344-352 cm as representing seal wallow conditions on or very close to the site. In these samples *Callitriche* pollen is markedly more abundant than elsewhere in the profile, and accounts for 65-88% of total dicotyledon pollen (Fig. 10). In modern wallows (Fig. 10) *Callitriche* reaches 95% of total dicotyledon pollen with *Cotula, Stilbocarpa* and other dicotyledons present in small amounts. On a dicotyledon-only basis the 294 cm sample is much poorer in *Callitriche* (20% of total dicotyledons), while at 80 cm it reaches 45% of total dicotyledons. The occurrence in the 394 cm, 344 cm and 294 cm samples of diatom suites rich in *Pinnularia atwoodii* is consistent with the interpretation from the pollen evidence, that
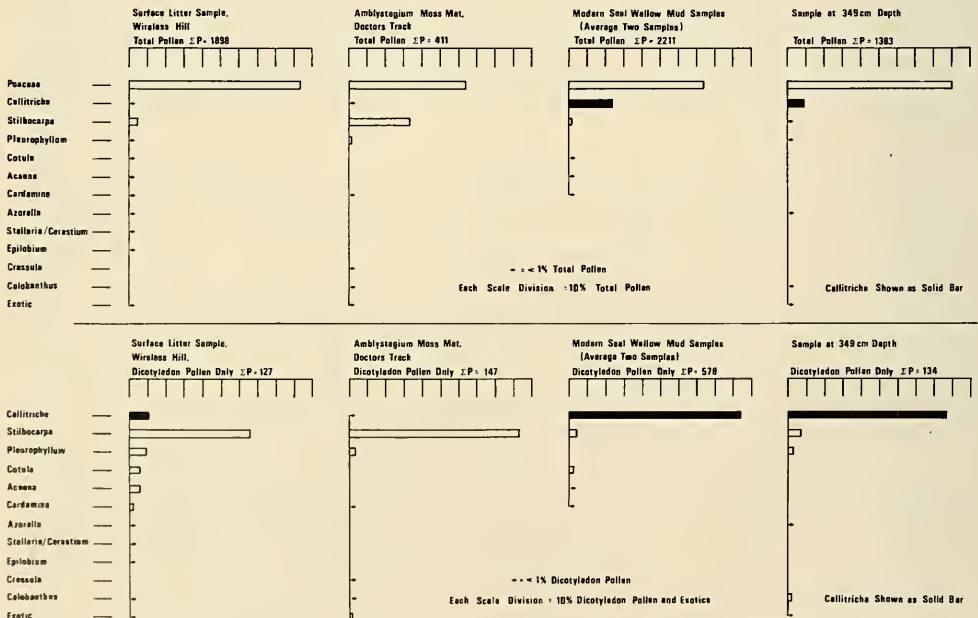

Fig. 10. Pollen diagram comparing analysis of a surface litter sample, *Amblystegium* moss mat, modern seal wallow mud and sample at 349 cm depth in profile. Upper diagrams show % total pollen. Lower diagrams show % based on total dicotyledon plus exotic pollen only.

the basal sequence of the profile represents an animal-disturbed area, most probably a seal wallow.

Since the basal *Callitriche* peak appears to represent seal wallow conditions, developed only at low altitudes, the pronounced peak in *Pleurophyllum* at 374 cm could appear anomalous, since *Pleurophyllum hookeri* is very common in subglacial herbfield (Taylor, 1955) at altitudes of about 200 m or more. *Pleurophyllum,* however, is also a major component of communities on the raised beach terrace at the northern end of the west coast of the island. Taylor (1955) mentions elephant seal destruction of *Pleurophyllum* patches at numerous places on this terrace. The pollen record could well represent elephant seal invasion of such an established community, close to the sea.

If the basal portion of the sequence represents the local presence of seal wallows, there are important implications in the record for the tectonic history of Wireless Hill. Seal wallows on top of the hill at its present altitude of 100 m are impossible. So steep are the slopes to the flat top that fixed ropes are provided to assist people in the climb. Seals could only wallow in the area if it were close to sea level. Wallows on Macquarie Island and other subantarctic islands occur on flat areas relatively close to the ocean, and elephant seals probably do not regularly go more than 15-20 m above sea level. If one accepts 20 m as the probable upper limit of elephant seal-modified vegetation, the conclusion seems plausible that, at about 5500 years BP, the Wireless Hill site, now at 100 m, can have been no more than about 20 m above sea level. Uplift of the site relative to sea level at average rate of 14.5 m/1000 years over the past 5500 years is implied. This rate is 3-4 times the maximum rate of uplift calculated for the marine terraces on the main part of the island (Colhoun and Goede, 1973).

The increase to a maximum, followed by a decrease, of *Stilbocarpa* pollen is explicable in terms of steady uplift of the site. On Macquarie Island, *Stilbocarpa polaris* is very common in a rather narrow altitudinal band at the base of the scarps which bound the island and on their lower slopes. Higher up the scarps as on the western side of Wireless Hill, *Stilbocarpa* gives way to dense stands of *Poa foliosa* tussock. The upper limit of this pure tussock grassland occurs at the scarp-plateau transition and may extend beyond it in favoured conditions. *Stilbocarpa* is particularly common in soil-slip and other bare areas on steep slopes (Taylor, 1955). Taylor regarded the presence of a mixed *Poa* tussock-*Stilbocarpa* community as a stage in succession to pure *Poa foliosa* tussock. One can imagine *Stilbocarpa* as having been common on steep, unstable slopes which could have developed on Wireless Hill during uplift, and then declining in importance at higher altitude as *Poa* tussock stands became more common at the top of the slope and on the edge of the plateau.

Radiocarbon dating of the base of organic deposits overlying a raised beach does not of itself provide dating of the uplift since there may be a considerable and unpredictable time lapse between uplift and establishment of vegetative cover. Colhoun and Goede (1973) commented on the probability, in a hyperoceanic environment such as that of Macquarie Island, of the immediate development of vegetation on any land surface lifted above the limit of marine erosion. With this we agree. Stone (1979) reports thin peat deposits on an 8 m raised beach on South Georgia. The ^{14}C dates for the Wireless Hill site imply development of vegetative cover only some 5500 years ago. Had the site been anywhere near its present altitude before that time, one would expect peat accumulation to have begun earlier. At 100 to 150 m altitude at both Finch Creek and Green Gorge peat was accumulating considerably earlier (about 10000 and 6900 years bp respectively) (Selkirk and Selkirk, 1983). The likelihood of peat accumulation at the same altitude on Wireless Hill being delayed several thousand years is remote. It is difficult to envisage complete removal of an older peat which originally overlay the cobbles and its replacement at a later stage by another

peat. Erosion by wind and/or water is unlikely to have removed peat from a flat-topped hill while peat accumulated elsewhere. Landslip would not remove material from an almost flat surface in any quantity, while landslip on the steep slopes near the site is unlikely to have left the beach deposit intact. It seems more likely that peat accumulation on what is now the top of Wireless Hill only began some 5500 years ago because it was only then that the site became clear of overwhelming marine influence.

The postulated rapid uplift of the Wireless Hill site can only be due to tectonic activity on the Macquarie Ridge. There is no evidence of any but slight relative sea-level changes in the period under consideration (Clark and Lingle, 1979). Large-scale isostatic readjustment following removal of an ice sheet can be ruled out, if glaciation of Macquarie Island has been moderate (Colhoun and Goede, 1974; Löffler and Sullivan, 1980). Glacio-isostatic readjustment is probably responsible for some low-level raised beaches on other subantarctic and antarctic islands. On South Georgia there is a series of Holocene raised beaches up to 7 m above sea level (Clapperton, 1971; Stone, 1974, 1976), and a series of raised beaches at higher levels (up to 52 m) which are much older, clearly predating a glaciation (Sugden and Clapperton, 1977; Clapperton *et al.*, 1978). Clapperton *et al.* suggest a date for the 7 m raised beach somewhere between 9500 and 4000 years BP. John and Sugden (1971) described high-level residual beaches, overridden by till, at altitudes up to 275 m in the South Shetland Islands block, possibly structurally linked to Patagonia, where late Tertiary tectonism produced raised marine features. Low level raised beaches occur on Marion Island series of lower raised beaches, the beaches at about 6 m dating at approximately 640 radiocarbon years (Sugden and John, 1973). On West Falkland raised beach deposits occur up to 69 m (Clapperton and Sugden, 1976), and it is suggested that the most likely explanation for the high-level beaches is tectonic movement of the Falkland Islands block, possibly structurally linked to Patagonia, where late Tertiary tectonism produced raised marine features. Low level raised beaches occur on Marion Island (Hall, 1978). The raised beach on Wireless Hill at 100 m, almost certainly Holocene, and overlain by deposits dating at about 5500 years BP appears to be in striking contrast with other subantarctic raised beaches.

The suggested rate of uplift for the Wireless Hill site is high. Movement along the fault line which separates Wireless Hill from the isthmus (Varne and Rubenach, 1972) must have been frequent, although there has been no reported movement on the fault line since discovery of the island. Single large earthquakes have been associated with uplift of the order of 10 m over small areas (Plafker, 1965).

Rates of tectonic movement quoted in the literature are lower than the postulated 14.5 m/1000 years for Wireless Hill. Suggate (1978) quotes uplift of about 10 m/1000 years at the Paring River locality on the Alpine Fault of New Zealand, the Alpine Fault being regarded as a northward extension of the Macquarie Ridge. Chappell (1974) and Chappell and Veeh (1978) used emergence of coral reefs above sea level to study tectonic movement in New Guinea and Timor. Rates of uplift in the Timor area range from 0.5 m/1000 years to 0.03 m/1000 years (Chappell and Veeh, 1978).

The presence of the distinct charcoal layer at 85 cm and the less pronounced charcoal band at 30 cm appears to be the first direct evidence for natural, rather than man-made, fire in the subantarctic. Barrow (1978) states that South Georgia has suffered no fire, while vegetation on the Falkland Islands has suffered from both fire and grazing pressure for some time. Further research on South Georgia may, of course, eventually give evidence of fire there. Fires have certainly occurred on Macquarie Island since sealing began there and Cumpston (1968) refers to several deliberately-lit fires. However, there is no reference to the effect of fires on vegetation. G. Copson (pers. comm.) has seen vegetation on Wireless Hill continue to burn after

having been accidentally lit, and believes a peat fire could burn for some time once started. J. Jenkin (pers. comm.) reports having watched fire from a burning rubbish heap on the main island spread into tussock vegetation, heat from the fire drying out the vegetation in front of it as it was fanned by wind. The only agent likely to cause natural fire on Macquarie Island is lightning, which Copson states is recorded on average at least once a year. A dry spell coupled with lightning strike offers the best possibility for fires. Although such events would be rare, over a period of thousands of years a number of such events could occur.

Macroscopic charcoal pieces from the 85 cm layer when viewed under scanning electron microscopy do not meet the criteria for charcoal put forward by Cope and Chaloner (1980). Cope and Chaloner, dealing with woody tissue, regarded the presence of homogeneous cell walls without visible layering as diagnostic of wood charcoal under the scanning electron microscope. Cell walls of the putative charcoal from Macquarie Island (Fig. 8) are clearly not homogeneous. However, very little is as yet known about charcoal pieces derived from herbaceous plants, and it is probable that tissues other than wood, charred under wet conditions, may give a charcoal differing rather radically from the type of wood charcoal usually encountered in sediments.

It is interesting that both fire events appear to correlate with an increase in *Callitriche* pollen. *Callitriche* may not only be coprophilous, but may also act as a colonizer of wet bare areas with high nutrient levels such as would occur after fire in tussock grassland. As there are no direct observations of recolonization by plants of burnt areas on Macquarie Island, it is not possible to be sure of this, however, as bird disturbance of vegetation may also account for the increase in *Callitriche* pollen at both 80 and 30 cm.

In summary, sediment, palynological, diatom and plant macrofossil analysis of samples from this profile show evidence of changing vegetation on the site. Having considered the possible alternatives, we feel that the available evidence is most appropriately interpreted as suggesting that this site was at or close to sea level about 5500 years ago when it began accumulating vegetation; that the plant communites, when close to sea level, were animal-, probably seal and/or gentoo penguin, disturbed; and that the sequence of vegetation changes in the profile reflects changes due to altitude as the site was uplifted.

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